Movement of liquid beryllium during melt events in JET with ITER-Like Wall

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** See the Appendix of F. Romanelli et al., Proceedings of the 24th IAEA Fusion Energy Conference 2012, San Diego, US*

MOTIVATION

•Beryllium is the low Z material selected as a plasma facing material for the wall in ITER

•During melt events the liquid beryllium can move due to gravity and Lorentz forces. Liquid metal motion changes the surface shape result in leading edges. The leading edges reduce power handling of the components and increase erosion.

•Hot spot formation on beryllium

•The only observation of the beryllium melting in JET can provide necessarily experience

EXPERIMENTAL RESULTS

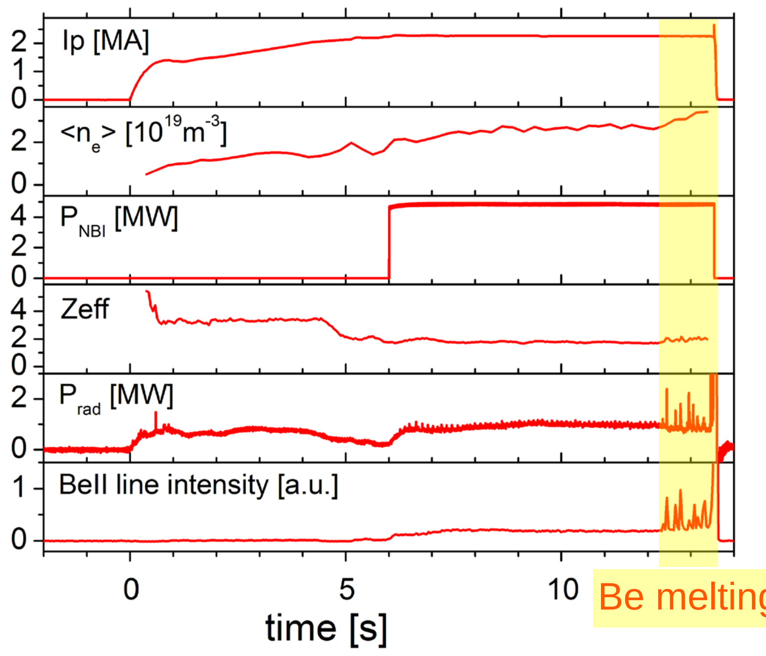

Figure 1: Main parameters of the pulse #83620

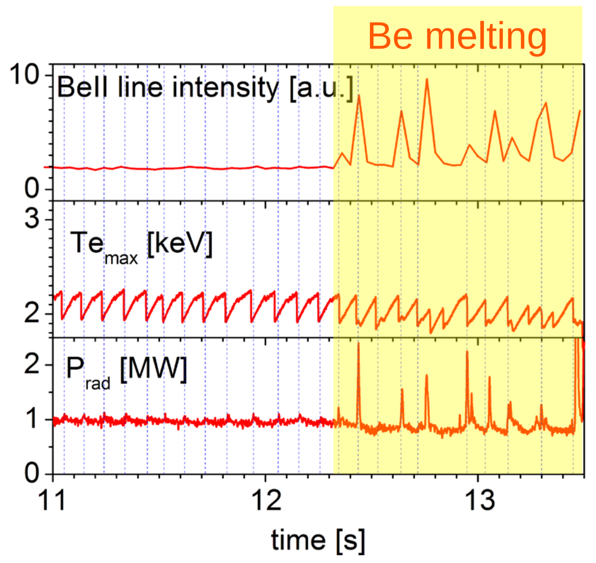

Figure 2: Correlation of liquid Be splashes with the sawtooth oscillations, #83620

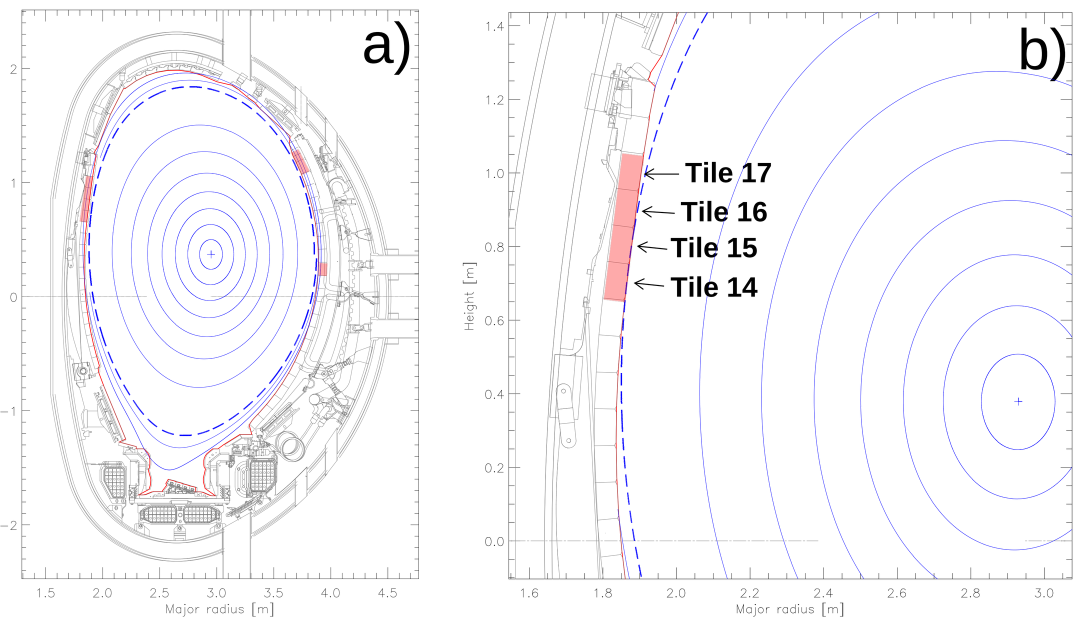

Figure 3: Magnetic configuration, #83620 t=13.3s

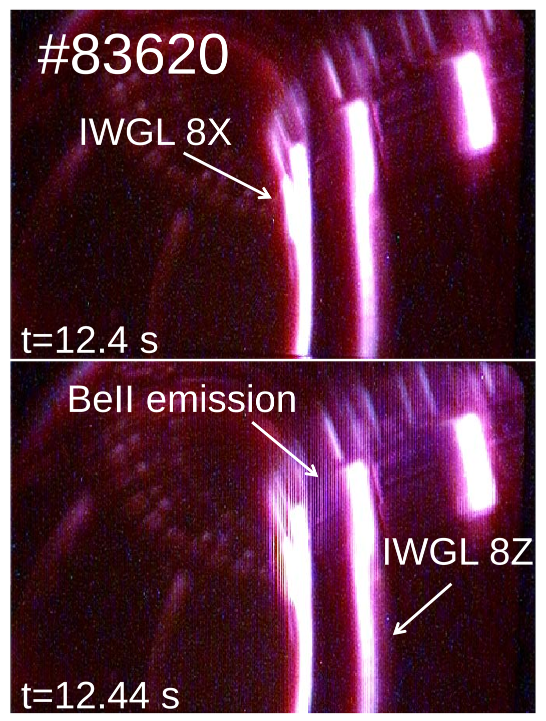

Figure 4: The light emission caused by liquid Be splash observed by KL12-O1WC video camera

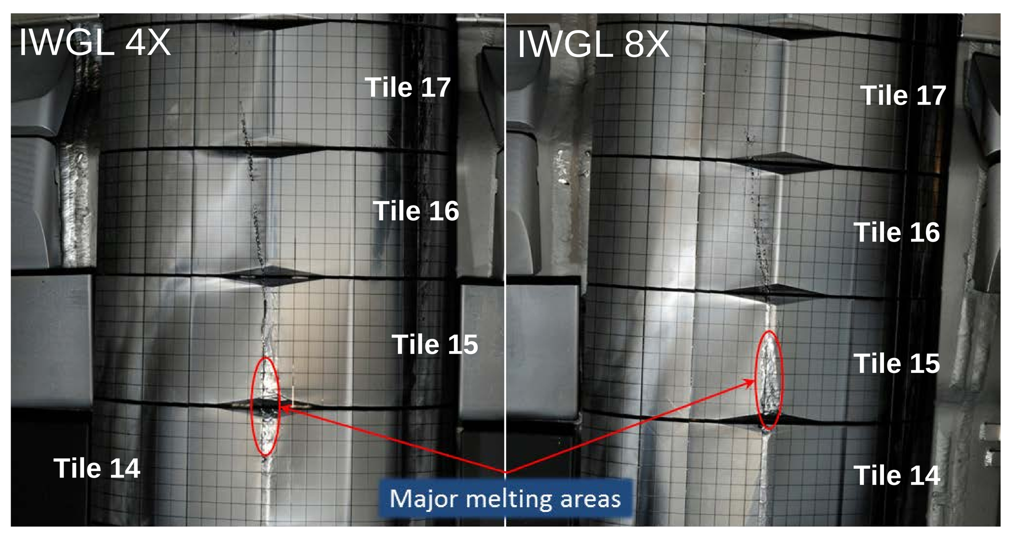

Figure 5: Beryllium melt motion on HFS

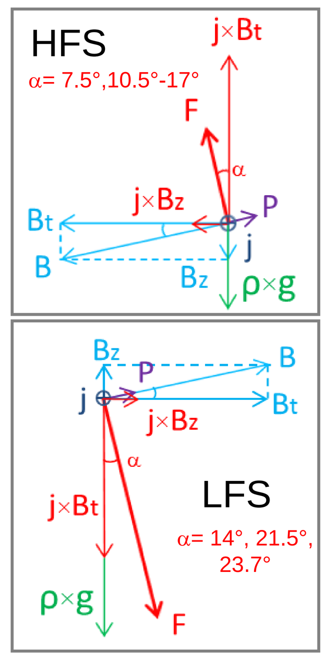

Figure 6: Force diagram

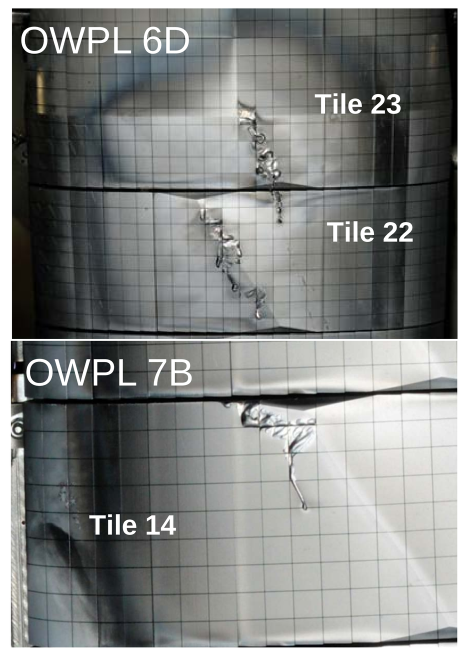

Figure 7: Beryllium melt motion on LFS

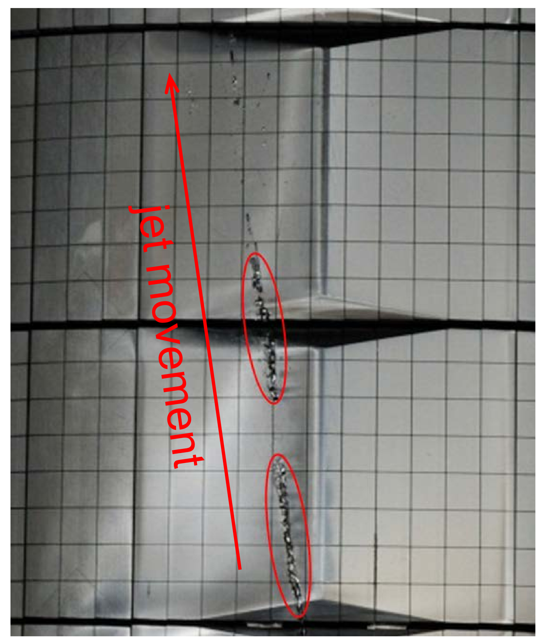

Figure 8: Liquid Be jet traces

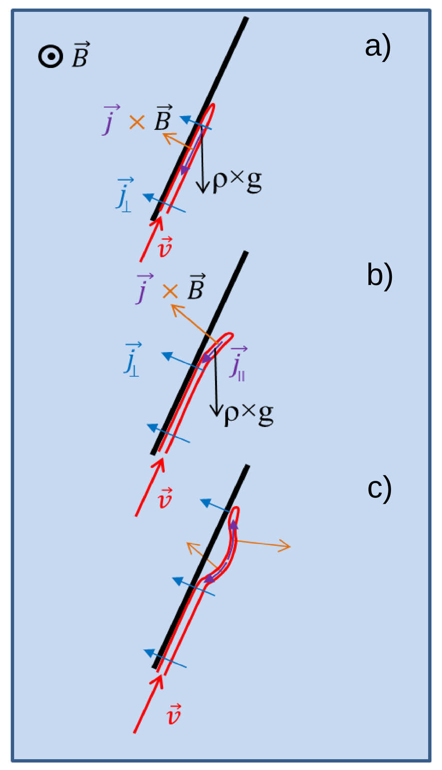

Figure 9: Metal jet movement along conducting surface

- No beryllium melting on the inertially cooled limiters observed in JET in divertor configuration
- Limiter discharges for power handling benchmark [1] lead to local melting due to toroidal asymmetries (T_{max}<980°C for limiter 8Z adjacent to limiter 8X and maximum heat flux to the 8Z limiter is about 3 MW/m^2)
- Steady-state melting over 1 s with periodical splashing
- Liquid beryllium splashing correlates with the sawtooth oscillations
- The liquid beryllium moved upward in HFS and downward in LFS
- Melt motion caused by Lorentz force due to current $j_\perp$ flowing to the surface and by plasma pressure
- Current density on the surface should be above 6 kA/m^2 to compensate the gravity force
- Liquid metal jet re-attaches quickly to the surface after detachment due to the increase of the current $j_\parallel$ flowing along the jet, which pushes the jet back to the surface.

DISCUSSION

Thermo-electron emission from Be and BeO

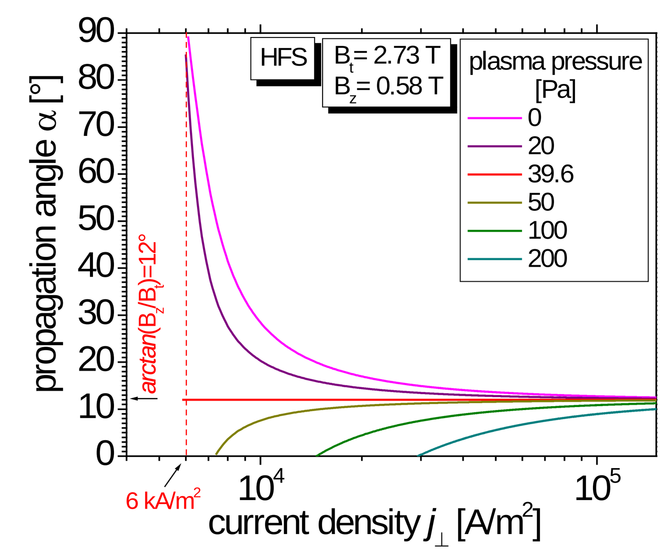

Figure 10: Calculated angle of 1mm melt layer propagation as a function of the current density to the surface and plasma pressure

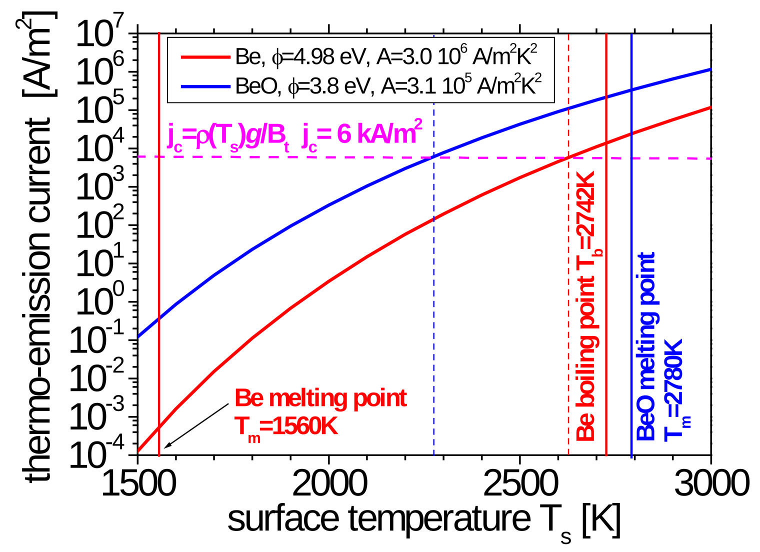

Figure 11: Calculated thermo-electron current as a function of surface temperature

- At the melting point, the thermo-electron emission current for pure beryllium is very small . The jxB force compensates the gravity force only at the temperature 100K below the boiling point.
- Beryllium oxide has higher thermo-electron emission current and the gravity force is compensated by the jxB force at the surface temperature of about 2284K which is essentially above the melting point of pure beryllium. It is unlikely to have BeO on beryllium surface under strong plasma flux
- For movement of liquid Be thermo-electron emission is not sufficient for both pure Be and BeO
- The motion of the liquid beryllium at the melting point temperature can be due to the secondary electron emission current. Similar liquid metal (stainless-steel) motion was observed in [2] and also can be explained by the secondary emission current.

Temperature bifurcation due to recycling of ionized vapor

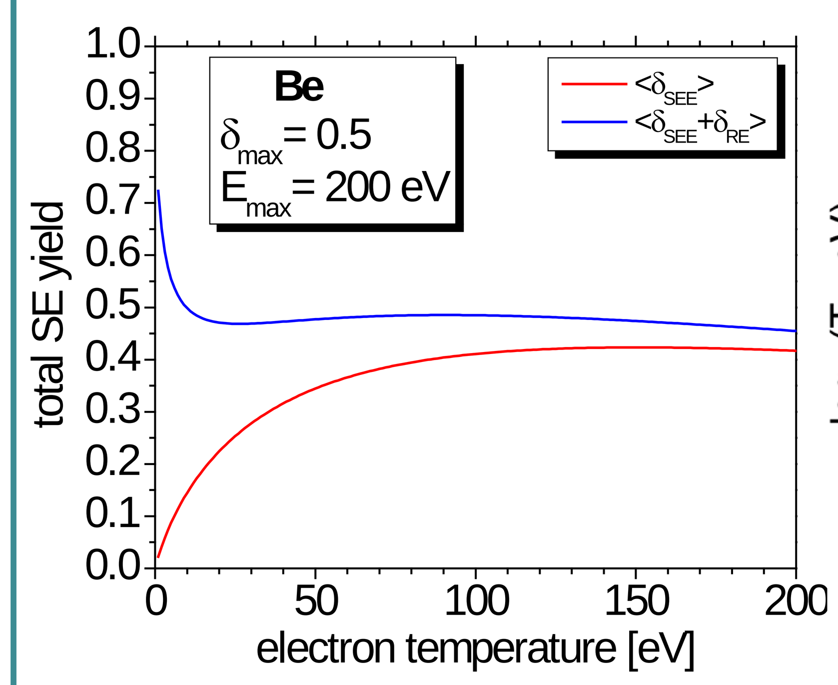

Figure 12: Calculated total secondary electron yields of beryllium : without and with backscattering versus electron temperature

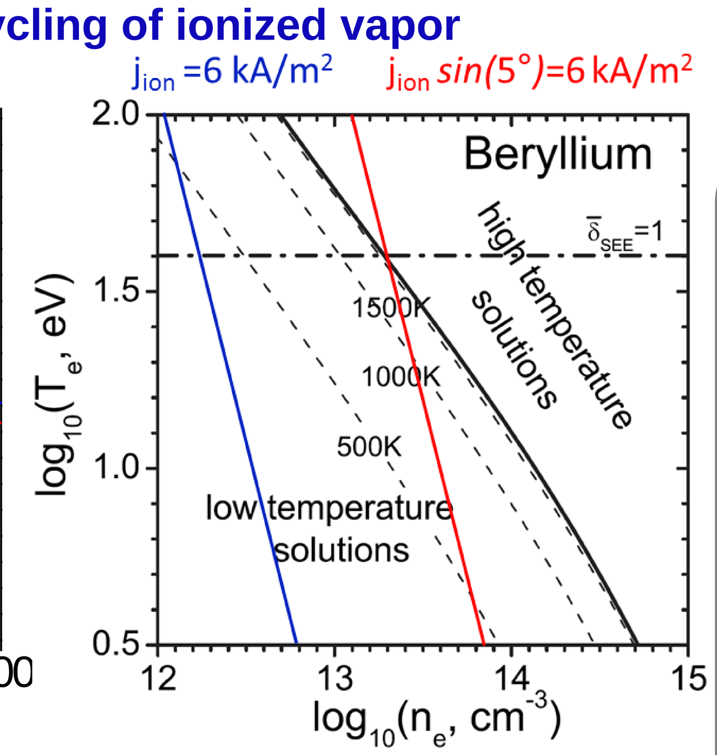

Figure 13: Calculated in [3] equilibrium beryllium temperatures as a function of the plasma parameters

- Heat flux to the hot surface increases due to recycling of ionized vapor [3].
- For beryllium for the surface temperature above 1560 K there is surface temperature bifurcation: the regions with low heat flux and low surface temperature can co-exist with regions with high surface temperature and high heat flux.
- For Te above 40 eV, the secondary emission from beryllium δ_{SEE} > 1 and secondary emission current is sufficient to move beryllium for the plasma parameters above blue and red lines on Figure 13,. for surfaces normal and tilted to the magnetic field lines respectively.

CONCLUSIONS

- Thermo-emission current which is important for the liquid tungsten motion against gravity [4] is too small for the case of liquid beryllium
- In contrast to liquid tungsten, pressure force due to plasma flow to liquid beryllium is comparable with Lorentz force
- For electron temperatures above 40 eV, the total secondary emission from beryllium δ_{SEE} >1 and its current could be sufficient to move the liquid beryllium.
- The current along the liquid metal jet moving on the conducting surface prevents the detachment of the jet from the surface.
- After the melt damage, beryllium limiters could operate afterwards in divertor configuration without defradation of the plasma performance

ACKNOWLEDGEMENTS

This work was supported by EURATOM and carried out within the framework of the European Fusion Development Agreement. The views and opinions expressed herein do not necessarily reflect those of the European Commission.

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